MAYMIR

Design of Reinforced-Concrete Water Tower & Steel Tank

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DESIGN OF REINFORCED-CONCRETE WATER TOWER AND STEEL TANK

BY

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I recommend that the thesis prepared under my supervision by EURIPIDES FAJARDO Y MAYMIR entitled Design of Reinforced-Concrete Water Tower and Steel Tank be approved as fulfilling this part of the requirements for the degree of Bachelor of Science in Civil Engineering.

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DESIGN OF REINFORCED CONCRETE TOWER AND STEEL TANK.

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PART I.

I. Introduction: General Discussion of Uses and Advantages.

There are two ways in which water is stored: in natural reservoirs or in artificial reservoirs. Of the last named division we have artificial lakes, stand-pipes and elevated tanks. The system to be decided upon is determined by local conditions or by the purpose for which the reservoir is to be used.

Where a reservoir needs to be artificially elevated, it is constructed as a stand-pipe--a tall tank resting on the ground,-or as an elevated tank either of steel, wood, or reinforced concrete, supported by a tower.

Beginning with the reinforced concrete construction, probably in no other way has concrete been more advantageously used than in the building of tanks. The reinforced tanks are easily constructed in any usual form. Small tanks are often placed on top of the house for house supply, and for fire use whenever needed.

Concrete tanks are used in various industries, as follows: in the manufacture of oil, wine, milk, molasses, pulp, glue, and a variety of other materials, both for the storage of the finished product and in the processes of manufacture. Some vegetable oils are said to have a deteriorating effect upon concrete, but through the use of the very excellent waterproofing compounds now available, concrete can be used

in the construction of tanks for these oils. Very naturally, the use most widely given to concrete tanks is for the storage of water, and probably nine-tenths of the tanks ~~built~~ are built for this purpose.

In choosing the location, size, and shape, we may divide tanks into two classes: those above the ground surface, and those below. In selecting the proper design the location must first be determined.

As it is not the purpose of this thesis to give a complete description of the construction of these tanks, a brief review of some of tanks already constructed will follow.

II. Description of Several Stand-pipes and Water Towers.

(A) An 80-Ft. Stand-pipe of Reinforced Concrete at Milford, Ohio.

The use of reinforced concrete in tank and bin construction has been extensive in both Europe and America. In most instances, however, these tanks and bins have been rather shallow in comparison with their lateral dimensions which is a form directly opposite to that of the ordinary water-works stand-pipe.

The stand-pipe to which this title refers is 81 feet high from base to roof, and the roof has a rise of three feet, making the total height of the structure 84 feet. The outside diameter is 15 1/2 feet. The shell at base is 9 ins. thick and maintains that thickness for 30 ft.; when it is reduced to 7 ins., and again at the height of 55 ft. to 5 ins. The reduction in thickness is made wholly on the inside of the

pipe. The structure has an inside and an outside ladder, and gives 78 ft. of net water space.

The foundation is octagonal with an inscribed diameter of 20 ft.; and 6 ft. deep. It was constructed of concrete composed of 1 part cement and 7 parts clean river gravel; about 44 per cent. sand and pebbles up to 4 ins. in diameter. On the top of this concrete slab, 1 x 1 x 1/8 in. T-bars were laid, radiating from the center to within 6 ins. of the outer edge. The shell was started directly on these T-bars, and after being carried up a sufficient distance the base outside the shell was covered with concrete 16 ins. deep and the base inside the shell with a 6 in. layer of 1 cement to 3 sand mortar and reinforced by a net work of verticals spaced 18 ins. around the structure and of horizontal rings spaced six to the foot for 30 ft., then five to the foot for 25 ft. and then four to the foot for the remainder of the height. These verticals and rings were 1 x 1 x 1/8 in. T-bars, connected at intersections by clamps to the forms. There was used about 25000 lbs. of steel, 270 barrels cement to 60 cu. yds. of gravel and 90 cu. yds. of sand.

(B) Reinforced Concrete Water Tower at Bordentown, N. J.

The water-works system of Bordentown, N. J., which was formerly owned by a private company that supplied water from the Delaware River, has recently been purchased and completely remodeled by the city. The river has been abandoned as a source of supply and a pumping station erected in connection

with a system of infiltration collector pipes, 3 miles inland, on the bank of a small tidal stream, which is an arm of the Delaware River. Pumps in this station elevate the water, supplied by the collectors through a 10 in. riser main, 3.3 miles long, to a 200,000-gal. steel tank on a reinforced concrete tower situated on a hill above the town. The distribution system is under direct pressure from this tank, the average pressure in the town being 60 lbs.

The infiltration collectors are built along the base of a bluff composed of sand and gravel and underlaid by a stratum of clay. This stratum of clay rises on a slight slope as it leaves the creek valley and comes to the surface several miles inland. The water from the overlaying gravel flows into the creek through a number of springs, and the ground in the vicinity of the station is completely saturated. A 12 in. collector extends along the base of the hill each way from the pumping station the total length of the two branches being 1,200 ft. One of these main collectors has an 8-in. lateral branch, 250 ft. long, laid up the valley of a small brook which heads in the hill. The other has three 8-in. lateral branches, with a total length of 800 ft. which tap springs in the hillside. An 8-in. collector, 400 ft. long is also laid up a ravine adjacent to the station and connects directly with the suction wells. The supply afforded by the collectors is ample and could be greatly increased by extending them. A 6-in. well 125 ft. deep, has been sunk in the bottom of the suction well, however, to insure a supply if for any reason

the water from the collectors is shut off.

The concrete suction well is 30 ft. in diameter and 34.5 ft. deep. It has 20-in. walls and a floor of concrete 4 ft. thick. Owing to the saturation of the ground much difficulty was experienced in its construction.

The pumping station is a 26.5 x 53.5 ft. one-story brick building. It is divided into an 18 x 26.5 ft. pump room and a 24 x 32 ft. boiler room. The floor of the pump room is depressed 10 ft. to form a pit in which the pumps are placed. A vertical compound duplex Worthington pump and a horizontal compound duplex Deane pump elevate the water from the suction well 200 ft. to the tank.

The reinforced concrete tower is described below. The tower is 100 ft. high. It is formed by 8 vertical columns and a hollow concrete cylinder 8 ft. in diameter.

The concrete footing on which the tank rests is a 16-sided polygon in plan. It is 6 ft. thick, 38 ft. in diameter at bottom and 32 ft. at the top. The columns are 3.5 ft. square, 3 ft. square, and 2.5 ft. square, from bottom to first balcony, from first balcony to second balcony, and from the second to the third, respectively. Each column is reinforced by four plain round rods, one near each corner. These rods vary from 1 3/8 in. in diameter to 1 7/8 in. diameter. Horizontal rods, 1/4 in. diameter are placed 12 in. centers around the vertical rods.

The price was $10,500 complete.

(C) Reinforced Concrete Stand-pipe at Westerly, R. I.

A reinforced concrete stand-pipe was built at Westerly, R. I., during the summer of 1910. This structure is of interest on account of some new methods used in the construction and also because of its appearance and water-tightness.

The town of Westerly is a town of about 9000 inhabitants. Its water supply is derived from driven wells, and is distributed by pumping.

Prior to 1911, the only reserve supply was contained in a steel stand-pipe having a capacity of 370,000 gal. Additional reserve was thought advisable, and as the old stand-pipe needed a thorough overhauling, it was decided to build a new one on Quarry Hill, very near the old one. Concrete was chosen as the material, in preference to steel, after the water commissioners had examined other concrete stand-pipes in New England.

The cement seemed to give the concrete a somewhat lighter color than usual, and this was increased by the lime which was added, the result being an almost white concrete. The forms were not absolutely waterproof at the joints, and the water running out caused a slight burr at the edge of each bevel. The finishing tiles of the dome are dark red and glazed, and forming a marked contrast with the light concrete give a distinctly pleasing appearance.

The stand-pipe is founded on hardpan, which at this point is only 5 or 6 ft. below the surface. The inside diameter is 40 ft.; the height from the floor to the over-flow is 70 ft.;

and from the ground to the top of the ventilator on the dome, is about 88 ft. The thickness of the wall at the floor is 4 ft,; tapers to 14 ins. at a height of 5 ft., and is of this thickness up to the water-line. The wall for the first 5 ft. above the ground has an outside diameter of 44 ft. 4 ins., then an ornamental moulding reduces it to 42 ft. 4 in., which is constant to the bottom of the triglyphs, 6 ft. below the water-line. Just above this there is a fillet 6 in. deep and projecting 4 in. Above the water-line there is a cornice 24 in. deep and projecting 30 in. This is surmounted by a parapet wall 4 ft. high. A Gustavino dome of red tile springs from a seat 2 ft. above the water-line. Its diameter is 41 ft. and its rise 13 ft.

A steel ladder, 1 ft. wide, of 1/2 by 1 1/2 in. flats and 3/4 in. rounds is secured by bronze bolts in cast iron sockets with 1 in. bronze faces, set into the wall at 16-ft. intervals. The rungs are 12 in. from center to center, but this spacing is reduced to 6 in. through the opening in the cornice. The ladder was erected in 16-ft. sections and the bottom is about 16 ft. from the ground. Over the parapet, the flats are replaced by 1 1/2 by 2 1/2 by 1/4 in. angles.

For construction purposes a frame tower, large enough for a 1-yd. Ransome auto dump bucket, was placed so that it cleared the outside edge of the cornice by about 1 ft. This tower had 6 by 6 in. uprights and was thoroughly crossboxed. A No. 2 Smith concrete mixer, run by steam, was set in a pit so that the materials could be conveniently dumped into the

hopper from the ground. The mixer emptied directly into the bucket, which was operated by a hoisting engine.

The boiler furnished steam for mixing, hoisting, and later also, for pumping water to the top of the wall for washing it. The concrete for the foundation, floor, and base was hoisted about 20 ft. and dropped into a chute. One section of this chute carried the concrete from the tower to the center of the tank, and from there a movable section delivered it in place.

(D) A 150,000 Gallon Reinforced Concrete Tank, Savannah, Georgia.

An example of modern reinforced concrete construction is found in the high service water tower recently completed by the Central of Georgia Ry. Co., at Savannah, Ga. The structure is made up of the supporting tower and two tanks, the upper compartment having 100,000 gals. capacity, and the lower one 50,000 gals.

The tower consists of a hollow, chimney-like shaft 188 ft. high, 35 ft. outside diameter at the ground line, with a taper which gradually diminishes until at a height of 75 ft. the shaft is 25 ft. in diameter from that point to the top. The tank bottoms consist of domes of reinforced concrete forming partitions in the shaft. The roof is conical and also of reinforced concrete.

The whole structure rests on a pile foundation consisting of 117 pine piles 40 ft. long driven 3 ft. on centers in three

concentric circles. The piles were cut off at an elevation of 3.75 ft. above sea level, which is below the line of permanent moisture. The concrete in the foundation was poured around the piles without the usual decking, but care was taken to see that the mass was so reinforced that the load would be distributed uniformly over the piling. This foundation reinforcement consists of 3/4 in. corrugated bars laid both radially and as concentric circles. Six of these circular lines of reinforcement are close to the outer edge of the foundation and grip the piles so as to prevent any tendency of the foundation to spread outward. Seven other circles help the radial reinforcement to distribute the pressure entirely over the foundation. The radial reinforcement of the foundation is made up of 300 bars 10 ft. long laid in a horizontal position 2 in. above the tops of the piles and spaced 6 ins. at the periphery.

The foundation tapers rapidly to meet the shell of the tower just below the ground level. This shell is 9 ins. thick at the ground line diminishing to 7 ins. thick at a height of 75 ft. and continuing thus for the remainder of the height of the tower. This shell is reinforced vertically with 1/2 in. corrugated bars placed near the center of the wall and spaced 24 ins. apart. The horizontal reinforcement is made up of 1/2 in. rods laid in a spiral. The pitch of this spiral being 1 ft. for each complete circumference. The horizontal rods are wired to the vertical rods at every intersection and all joints are lapped 24 ins.

The domes which form the bottoms of the two tanks are also reinforced with 1/2 in. rods and an extra amount of reinforcement is used in the portion of the shell which forms the walls of the tanks and is thereby subjected to hydrostatic pressure.

The tower is lighted by 8 x 30 in. windows arranged in the form of a spiral, each window being 8 ft. higher than the one preceding, and 20° in advance. In each of these window openings a pane of double thick glass has been placed and securely plastered with neat cement mortar. Three larger windows and a panel door have been provided at the bottom of the tower to make that portion serviceable as a storage room.

(E) The Anaheim Water Tower.

When the reconstruction of the water works for the city of Anaheim, in southern California, was first considered, the problem of a structure for an elevated water supply was one that had to be solved, the immediate surrounding country being very level with no natural reservoir site available. The population supplied is about 3,500 and it was necessary to have a storage capacity of 175,000 gals. with a minimum head of 60 ft. Bids were called for upon specifications for an elevated hemispherical-bottomed steel tank on steel towers and for a tank and tower of monolithic reinforced concrete construction. The specifications for the concrete tanks required that bidders must be able to show successful examples of reinforced construction either of tanks, stacks or structures of a similar nature.

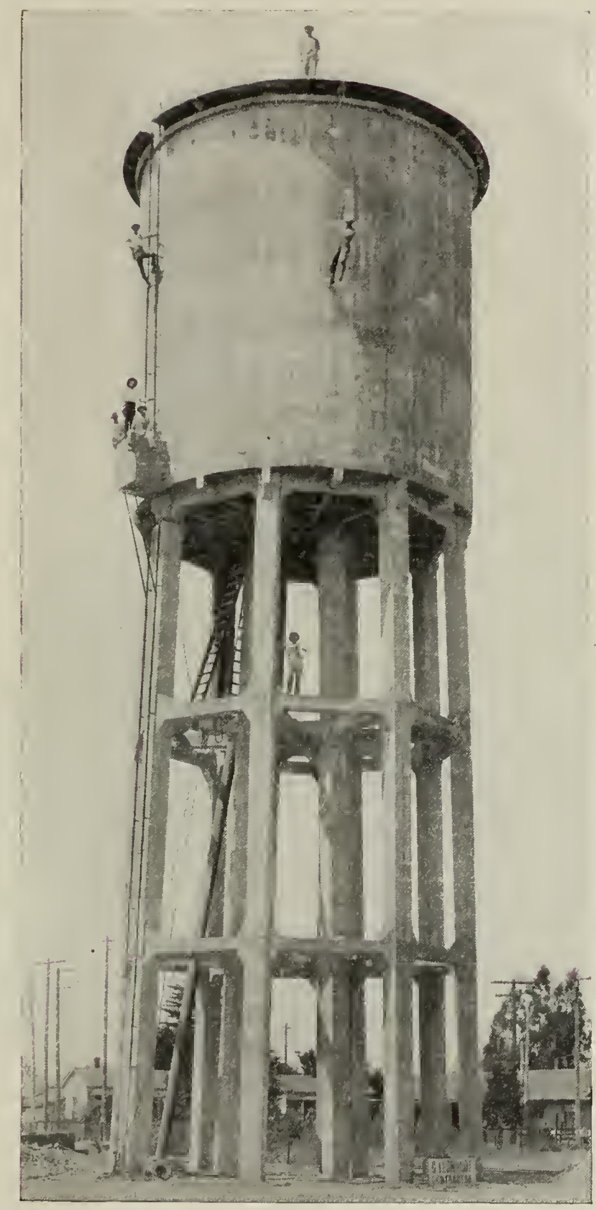


FIG. 25.—The Anaheim Water Tower built in 1907 for the Anaheim Water Company, at Anaheim, California; Mr. C. Leonhardt, of Los Angeles, California, contractor. This is not only a water tower, but a reinforced concrete tank. Some idea of the magnitude of the work can be had when we consider that the extreme top of the tank is 112 feet above the ground; the tank being 30 feet in diameter, 38 feet in height, and is supported by concrete posts 60 feet above the ground. The tank has a capacity of 180,000 gallons or 3600 barrels. The walls of the tank are 3 inches thick at the top and 5 inches at the bottom. The posts are 16 inches square; the cost of the work is $11,400, and amounts to only about 75 per cent. of the lowest estimate on a steel tank and tower of equal dimensions. About 800 barrels of Portland Cement were used in the work.

The bids for steel tanks and towers range from $9,200 to $12,500, while for reinforced concrete tanks and towers two bids were received; one for $10,400 which was accepted, and the other a little higher. The greater durability, reduced cost of maintainance and better appearance led the city trustees to accept the reinforced concrete structure.

The tank is approximately 30 ft. 3 in. in diameter and has a clear interior depth of 32 ft. It rests on twelve reinforced concrete columns, each 22 in. square and 60 ft. 2 in. long; eight of them being placed equidistantly on the circumference of a 33-ft. circle and the other four on the circumference of a 4-ft. 4-in. circle. The columns are braced by two series of horizontal struts at the third points of the length of the columns but no diagonal bracing in vertical planes is used. The batter of the columns and the manner in which they are built into the foundation slab and the tank floor are intended to provide for the lack of diagonal bracing. The horizontal struts evidently contribute to the rigidity of the tower by dividing the columns, in effect, into three compression members.

(F) Stand-pipe for Attleboro, Mass.

Among the later and less universal uses of reinforced concrete is the construction of stand-pipes for the water supply of towns. There has been built within the last year at Waltham, Mass., a water tank of reinforced concrete, 100 ft. in diameter and 37 ft. high. This tank, together with one at Fort Revere, Mass. and the one described in this article, are

FIG. 28.—A reinforced concrete water tower at Attleboro, Mass. This was built by the Aberthaw Construction Company of Boston, and was necessitated owing to the inadequate fire protection and lack of water for domestic purposes. A steel standpipe of the same dimensions would have cost $3135 more than one of concrete. The standpipe is 118 feet high and 50 feet inside diameter. The walls are 18 inches thick at the ground and 8 inches thick at the top; the foundations running 7 feet below the ground level. Concrete was mixed in the proportion of 1 part cement, 2 parts sand and 4 parts crushed stone. The tank was, of course, thoroughly reinforced.

This is probably one of the most notable reinforced concrete tanks ever built in the United States.

FIG. 20.—A reinforced concrete elevated wash-water tank built for the Louisville Water Company's filtration plant. Height over all 80 feet, elevation of tank above ground level 46 feet 2 inches.

the only ones of any size known to have been built.

The first two great problems in the design of a stand-pipe are, first, to insure strength to resist the water pressure, and, second, to make the structure water-proof. These facts have been stated before, but I restate them for emphasis. In a non-elastic material like concrete, the immense pressure at the bottom of a 100-ft. column of water makes the tendency to expand and open cracks in the side walls a dangerous possibility and the proper reinforcing of these side walls together with the right kind of water-proofing are the things toward which the designer's efforts are directed.

The town of Attleboro, Mass., was supplied with water up to the spring of 1904 from a wrought-iron stand-pipe 30 ft. in diameter and 125 ft. high, holding 600,000 gals. of water. In March, 1904, a break in the distribution line immediately after a fire, showed the authorities the necessity of building another larger storage reservoir for the water, one holding at least 3,000,000 gals. if possible. There was neither space nor location for a reservoir of such a capacity but an extremely convenient location for a stand-pipe was available. Owing to difficulties in design, however, it was decided to build a stand-pipe of only 1,500,000 gals. capacity.

For the following reasons, it was decided to construct a reinforced concrete stand-pipe: (1) The lowest side plates in a steel stand-pipe of the size required (50 ft. diameter and 100 ft. high) were computed to be 1 3/4 in., which is the thickest plate rolled by any of the steel companies.

(2) The carbon dioxide would have no effect on the concrete and would obviate the difficulties of removing rust and also the danger of corrosion of steel. (3) The life of reinforced concrete is very indefinite but is longer than steel which is only 20 years. (4) The reinforced concrete construction ran $3,000 less than steel construction.

Bids therefore were asked for for a reinforced concrete stand-pipe. The dimensions were specified. In September, 1904, the contract was awarded to the Aberthaw Construction Company of Boston, Mass.

The structure as built is 50 ft. in diameter, 106 ft. high from the elevation of the inside of the bottom of the tank to the top of the cornice. The walls are 18 ins. thick at the bottom and 8 ins. thick at the top. The inlet pipe rises to 40 ft. above the bottom and the water is compelled by check valves to leave the tank through a 24 in. pipe in the bottom, thus insuring circulation.

The foundation, which is on good solid hardpan, is of 1:3:6 concrete, 4 ft. deep on the exterior and 18 ins. under the floor, with 1/4 in. bars spaced 9 ins. center to center, and 3/8 in. bars 12 in. center to center horizontally.

As a matter of interest, the cost of 1:2:4 concrete for the walls was $13.95 per cu. yd.

(G) The Steel and Concrete Water Tower at Grand Rapids, Michigan.

As a part of the improvement of the distribution system of the municipal water-works at Grand Rapids, Mich., a 885,000

gal. water tower has been erected at a point about four miles from the pumping station. This tower acts as a pressure equalizer, and also holds a reserve supply for the section of the city adjacent to it. One pipe serves both as an outlet and as an inlet so the water enters the tank during the low demand, and is drawn from it when the quantity of water required exceeds the capacity of the mains feeding that section. The tank occupies quite a prominent site in a residential district, at an elevation somewhat above that of the balance of the city. On account of the location and the prominence of the site a structure that would not be a blemish on the landscape was especially desirable. The distance from the pumping station, and the fact that the tank was to be supplied by a main which is a part of the distributing system, made it necessary that the tank be protected from the frost, on account of the great fluctuation in the height of the water which would necessarily take place, causing danger of failure due to falling ice.

The conclusion was accordingly first reached to construct a reinforced concrete tower, enclosed by a shell or curtain wall of reinforced concrete, properly treated to be in keeping with the surroundings. Failure to secure satisfactory proposals for building a tower of this type, however, led to the design of a steel tank mounted on a low reinforced concrete base, and enclosed by a casing tower of reinforced concrete. Favorable bids for the execution of this design were received, so the combination tower was built. The contract was divided into two parts; one comprising all of the concrete was awarded to Mr. J. P. Ruache, a local contractor, and the

other, consisting of the steel tank, to the Rodgers Boiler & Burner Co.

The Steel tank, 50 ft. in diameter and 60 ft. high, stands on a substructure, consisting of a reinforced concrete inverted ground arches. This foundation is carried 7 ft. below the surface of the ground, and is shaped in plan like a twelve-sided polygon, having an enclosing circle of 67 ft. 10 ins. diameter. The arches have a clear span of 5 ft. and are 24 in. thick at the columns and 12 ins. thick at the crown. The footings spread the weight of the structure over the entire base so as to give loading of 4,300 lbs. per spuare foot on the soil, which is clean sharp sand. On this footing is erected a series of reinforced columns to carry the steel tank. Twelve columns are spaced around the circle described by the sides of the tank, one being placed at each angle of the enclosed twelve-sided polygon. The interior of this polygon is occupied by columns in regular transverse and logitudinal rows spaced 7 ft. apart on centers in both directions. The columns are connected by beams and girders, thus forming the supporting system of a 12-in. reinforced concrete floor on which the tank stands.

Around the steel tank is a twelve-sided curtain wall of reinforced concrete, 4 in. thick, carried by a separate series of 12 columns placed around the outside edge of the twelve-sided footing that also carries the tank columns. Surmounting the curtain wall is a heavy annular girder, cast monolithically with a cornice and a parapet wall. This annular girder is

designed to distribute the thrust of the dome. The cornice and parapet wall are detailed so as to give the proper porportions to the structure as a whole, and largely to conceal the appearance of the smooth, flat top of the dome. The latter has a span of 57 ft. and a rise of 10 ft., is 4 ins. thick at the crown and 6 ins. thick at the springing line. The reinforcement consists of No. 10 expanded metal.

The connection between the tank and distributing system is a 16-in. pipe carried through the footing and laid on the bottom slab of the latter to near the center of the tank. This pipe is controlled by a hand-operated gate valve. A space 7 x 14 ft. in plan between two rows of columns and the riser of an 8-in. washout pipe is also placed in this enclosure .

The forms for the curtain walls were built up in sections 4 1/2 ft. wide and 16 ft. long, corresponding in length to the width of the sides of the curtain walls. These forms were entirely independent of the falsework, being braced from and wired to the steel tank.

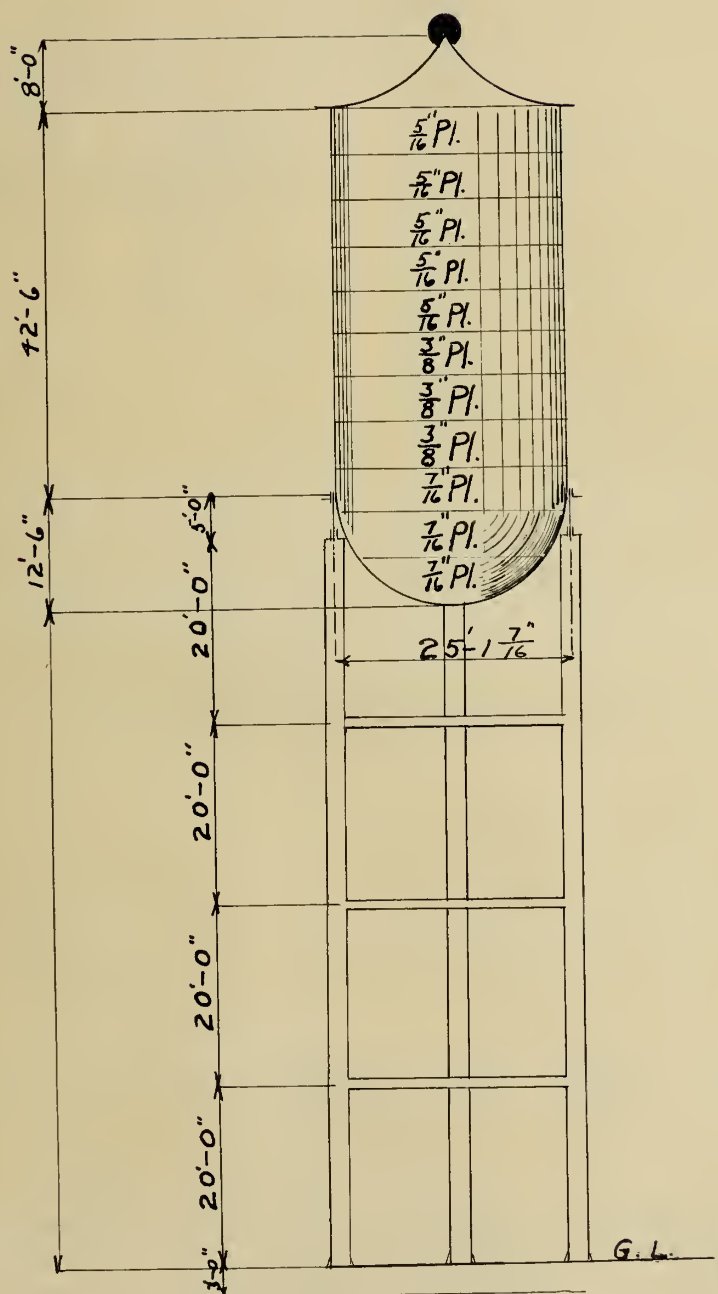
The concrete was poured to a depth of 4 1/2 ft. at one time, entirely around the wall, and special provision was made to avoid joints whenever the placing of the concrete was interrupted.

Three grades of concrete were used, as follows: Grade 1,-- for foundations, columns, and other work over 6 ins. thick, up to the bottom of the girder under the tank, 1 part Portland cement, 3 parts sand, and 6 parts screened gravel, having maximum dimensions of 2 ins; Grade 2,-- for the remaining portion of the work, except the dome, 1 part Portland cement,

3 parts sand, and 6 parts screened gravel, having maximum dimensions of 1 in.; Grade 3,-- for dome, 1 part Portland cement, 2 parts sand, and 4 parts screened gravel with maximum dimension of 1 in.

The complete structure cost $29,500, the steel tank representing an expenditure of $11,000.

PLATE I.



DESIGN
OF A 187,000 GALLONS
REINFORCED CONCRETE
WATER-TOWER
WITH
STEEL TANK
Scale $\frac{3}{64}" = 1'$

April 15, 1913 Eng. E. Fajardo

PART II.

I. Design of Roof.

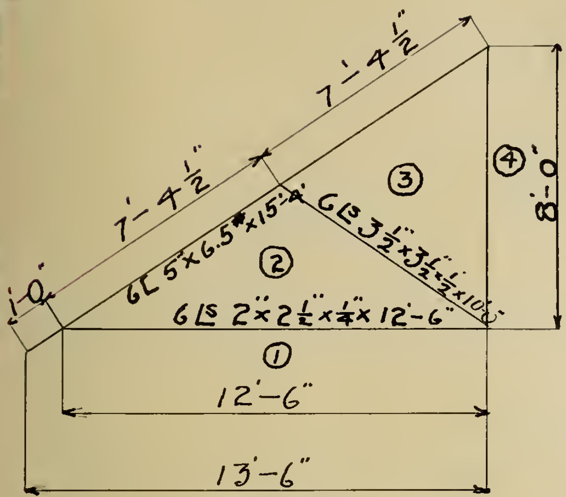


Fig 1.

(A) Dead Load on Roof.

By specification, 3 lbs. per sq. ft. is the weight of corrugated steel.

Roof pitch = 1/3.

Snow load = 15 lbs. per hor. projection of roof.

Then:

Total D. L. on roof due to corrugated steel $= w\pi r\sqrt{r^2 + h^2}$

where w = wt. per sq. ft. of roof

r = radius of hollow cone of roof

h = height " " " " "

Then, $3 \times 3.1416 \times 13.5\sqrt{13.5^2 + 8.5^2} = 2040$ lbs.

Dead Load due to snow.

Snow load on surface $= 13.5^2 \times 3.1416 \times 15 = 8570$ lbs.

(B) Design of 6 Bents which are Assumed to be used in the roof.

Load taken by one bent $= \frac{8570}{6} \times \frac{12.5}{14.8} + \frac{2040}{6} \times \frac{12.5}{14.8}$

$= 1497$ lbs.

M. max $= 1/8 \times wl^2 = \frac{1497 \times 14.8 \times 12}{8} = 33{,}300$ pound-inches.

$\frac{M}{S} = \frac{I}{C} = \frac{33{,}300}{10{,}000} = 2.08$ in.^{4}

By Cambria, 6[5" x 6.50 lbs. x 15' - 9"

(C) Design of Six Angles Designated in Roof as Members (2), (3).

Taking it as a column; then as before, 1497 lbs. is used by it. Assuming a 3 1/2 x 3 1/2 x 5/16 in. angle

By Cambria, r = 1.08, or $l/r = \frac{12 \times 10}{1.08} = 111$

$$S = 16{,}000 - 70 \frac{l}{r}$$

$$= 16{,}000 - 70 \times \frac{12 \times 10}{1.08}$$

$$= 8820 \text{ lbs.}$$

Area required $= \frac{1497}{8820} = .17$ sq. in. Area given by angle = 2.09 square ins.

(D) The member (1) (2) is designed to be minimum size, or 2 x 2 1/2 x 1/4 ins.

II. Design of the Steel Tank.

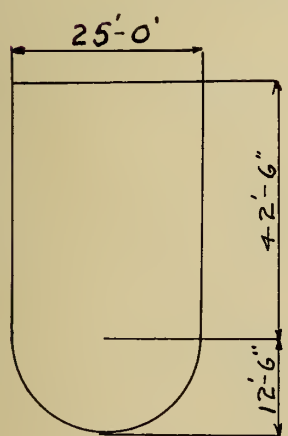


Fig 2

(A) Size of Tank.

The capacity assumed is 187,000 gals.

Assuming the diameter = 25'-0"

Capacity of cylinder $= \frac{1}{4}\pi d^2 h$

Capacity of hemispherical bottom

$$= \frac{1}{12}\pi d^3$$

$$\text{Total} = \frac{1}{4} d^2 h + \frac{1}{12} d^3 \qquad (1)$$

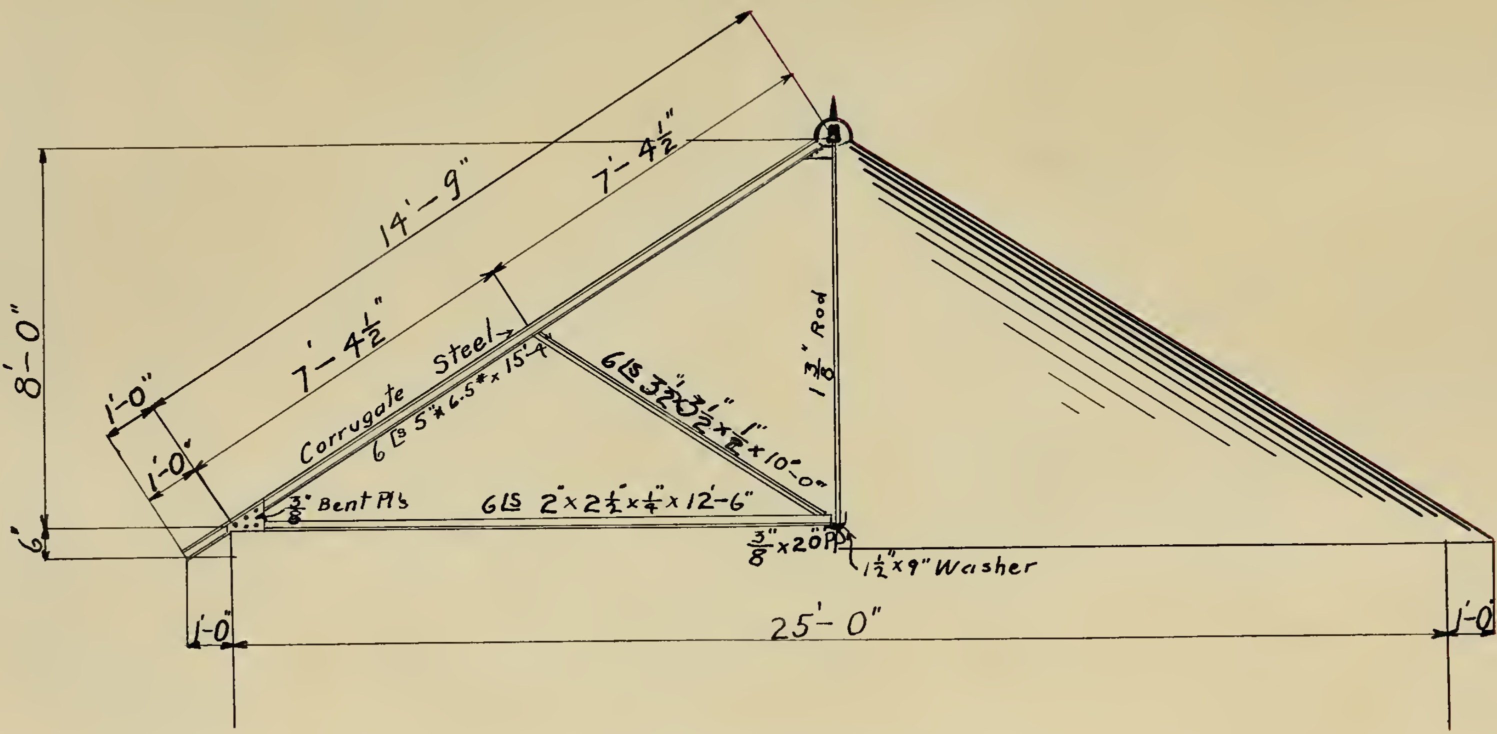
Substituting in equation its known values,

$$\frac{1}{4} \cdot 3.14 \times 25^2 h + \frac{1}{12} \times 3.14 \times 25^3 = \frac{187{,}000}{7.48}$$

from which,

h = 42 ft. 6 ins.

PLATE 2



DETAILS
OF ROOF
Scale: ¼" = 1'

(B) Thickness of Plates (For 50 % eff., 60% eff., and 70% eff.)

If: S = stress per lineal inch of pipe

h = distance in feet of any point below the top

d = diameter of pipe in feet

r = radius in feet

t = thickness of shell in inches at any given point

e = efficiency

s = stress per sq. inch

$$S = \frac{62.5hd}{2 \times 12} = 2.6hd$$

$$s = \frac{2.6hd}{t}$$

or, $t = \frac{2.6hd}{s}$ (2) $\qquad t = \frac{2.6hd}{e \times s}$ (3)

The safe tensile stress on net section where thick ice is to be expected = 12,000 lbs. per sq. in., and sometimes 10,000 lbs per sq. in.

Substituting in (3)

$$t_1 = \frac{2.6 \times 55}{12000 \times 50} = .595 \text{ in.}$$

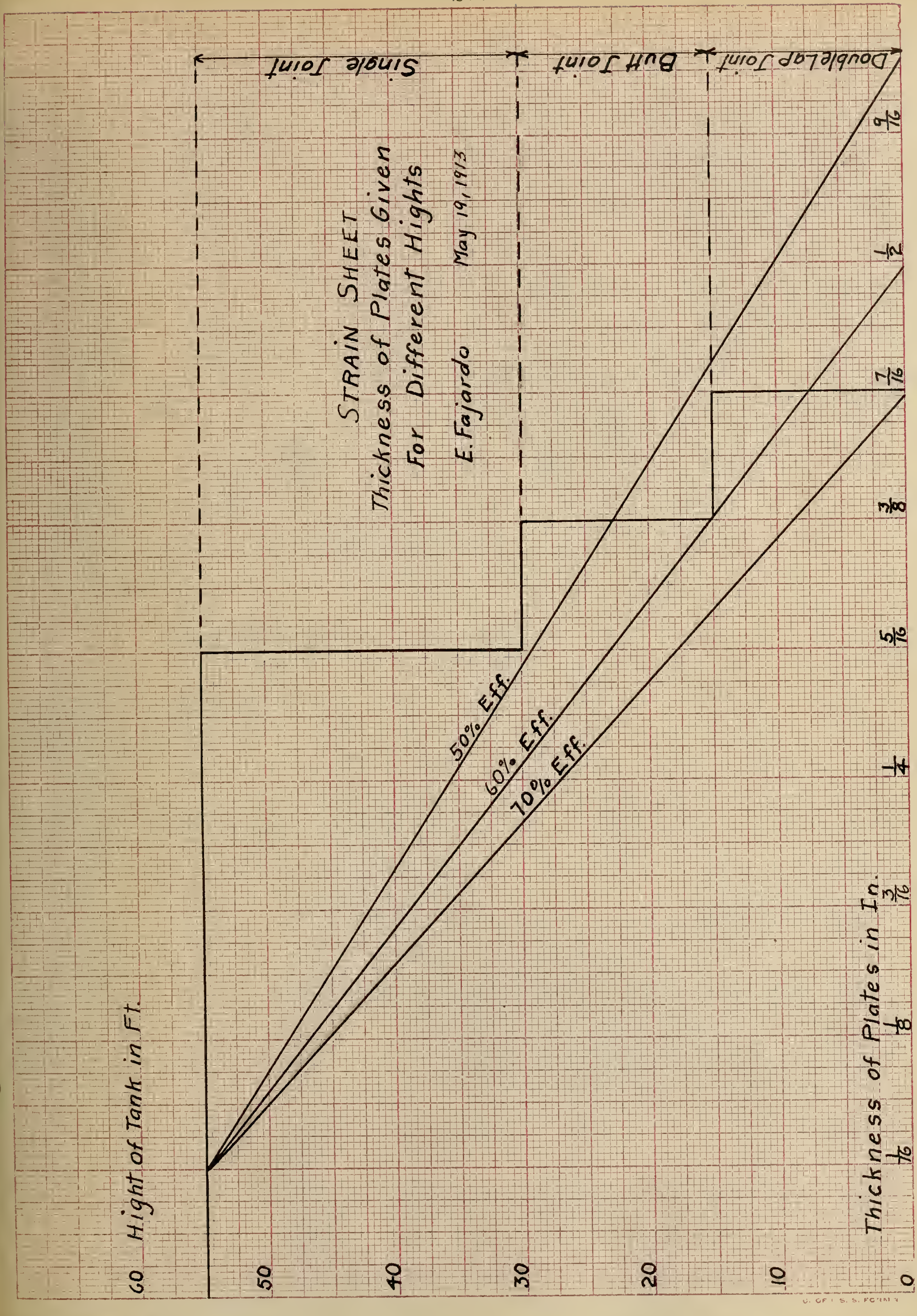
$$t_2 = \frac{2.6 \times 55}{12,000 \times 60} = .495 \text{ in.}$$

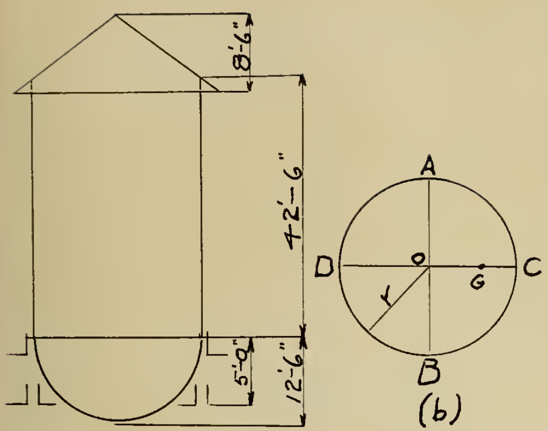
$$t_3 = \frac{2.6 \times 55}{12000 \times 70} = .425 \text{ in.}$$

With these values a Strain Sheet, as shown in diagram, is drawn.

III. Design of the Circular Plate Girder to support the Steel Tank.

(A) Stress in the Circular Girder.


STRAIN SHEET
Thickness of Plates Given
For Different Hights
E. Fajardo
May 19, 1913
Single Joint
Butt Joint
Double Lap Joint
50% Eff.
60% Eff.
70% Eff.
Hight of Tank in Ft.
Thickness of Plates in In.
0
10
20
30
40
50
60
1/16
1/8
3/16
1/4
5/16
3/8
7/16
1/2
9/16



(a) (b)

Fig 3.

The circular girder sustains the weight of the steel tank and roof; and weight of plate girder itself.

See Fig. 3 (b). If G represents the center of gravity of the load on the half-girder. The distance OG = $\frac{2r}{\pi}$; here r = radius of circular girder. Weight of water in tank = W.

$\frac{W}{2}$ = weight on half girder.

Finding moment about the center line AB, then,

$$2M_y + \left(\frac{W}{2} \times \frac{2r}{\pi}\right) - \left(\frac{W}{4} \times r\right) = 0$$

$$M_y = \frac{Wr}{2}\,(1/4 - 1/\pi)$$

$$= 0.03415\ Wr \qquad (4)$$

(B) Weight carried by Girder.

(1)	Corrugated steel..	2040
	Snow load on roof.	8640
	6 [5" x 6.50 x 15' - 9".	615
	6 angles 3 1/2 x 3 1/2 x 5/16 x 10' 0"	432
	6 angles 2 x 2 1/2 x 1/4 x 12' 0" . . .	170
	One rod, 1 3/8" x 8'	40
	Total Weight of roof	11,937 lbs.

(2) 15' of 7/16" shell..........21,000

15' of 3/8" shell 18,000

25' of 5/16" shell 25,000

Total weight of Steel Tank 64,000 lbs.

(3) 2 bottom angles 6"x6"x$\frac{9}{16}$"x78'-6" 3,440

5/16 x 60 in. web-plate x 78'-6" 5,000

1 top angle 6"x6" x9/16"x 78'-6" 1,720

Total weight of Girder 10,160 10,160 lbs.

(4) First Total . . . . 86,097 lbs.

10 o/o allowance overweight 8,610 lbs.

(5) Allowance: laps 5,000

rivets 6,000

angle stiffeners . 6,000

Total weight of allowances 17,000 lbs.

(6) Wt. of 187,000 gals. of water . . . . 1,567,000 lbs.

(7) Second Total . . . . 1,678,707 lbs.

(C) Bending Moment due to total Weight.

From formula previously given, the bending moment of the girder at the point of support where four columns are used is 0.03414Wr, here W is the whole weight and r the radius of the tank in inches. By substitution in (4):

0.03414 x 1,668,000 x 12.5 x 12 = 8,500,000 pound-inches.

(D) To find if the above assumed Circular Girder is Strong enough to counteract the Bending Moment above found.

(1) Area of Girder,

2 bottom angles 6" x 6" x 9/16" 12.88 sq. in.

5/16" x 60" web-plate . . . . . 18.75 " "

1 top angle 6"x6" x 9/16" . . 6.44 sq. in.

Total section area . . . . 38.07 square inches

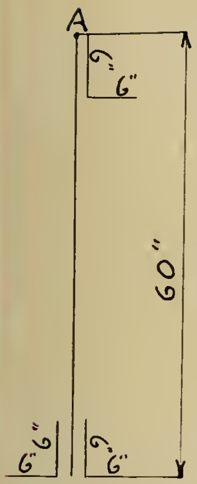


Fig 4.

(2) Center of Gravity,

Taking moment about point A:

$$12.88(60 - 1.71) + 18.75 \times \frac{60}{2} + 6.44(6 - 1.71)$$

$$= \text{c.g.} \times 38.07$$

or, $\text{c.g.} = \frac{134}{40.07} = 35.25$ ins. from A.

(3) Moment of Inertia;

$$I = 2 \times 22.07 + (12.88 \times 24.8^2) + \frac{60^3 \times \frac{5}{16}}{12}$$

$$+ (3.5^2 \times 18.75) + 22.04 + (6.44 \times 29.24^2)$$

$$= 19{,}386.2 \text{ in.}^4$$

(4) Resistance Moment,

$$M = \frac{SI}{C} = 16000 \times \frac{19386.2}{35.25}$$

$= 8{,}860{,}000$ inch lbs. which is larger than the moment found above.

(E) Design of Stiffeners.

(1) According to Cooper's specification, Art. 47, they should be placed at certain intervals whenever the unit shear is greater than $S = 10{,}000 - 75 \times \frac{74}{3/8} = -4800$. That is whenever the unit shearing stress is greater than zero at distance not to exceed 5 ft.

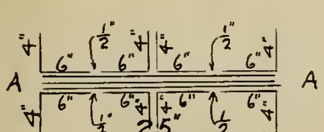


Fig 5

Fig. 5 represents 8 stiffeners at each one of the four supports.

(2) assuming 8 angles 6" x 4" x 3/4"

area of 8 angles = 8 x 6.94 = 55.5 sq. ins.

I_{AA} = 8[8.68 + 6.94 (1.08 + 23/32)]

= 169.44 in.^{4}

(3) $r = \sqrt{\dfrac{169.44}{55.52}}$

= 1.75 in.

(4) By Cooper's Specification,

allowable stress = 19000 - 45 $\frac{l}{r}$

Then requird area = $\dfrac{\text{Weight taken by one support}}{\text{all}}$

or, $= \dfrac{417,000}{10,000 - 45 \times \dfrac{58.87}{1.75}}$

= 49.7 sq. ins.

which is smaller than the area given, or 55.52 sq. ins.

(5) Between supports the same size stiffeners is used, but in pairs for each one of the intermediate points. Three points between supports are assumed to carry stiffeners. They are spaced 4 feet 7 1/2 ins. between rivet lines.

(6) Number of Rivets in each Pair of End Stiffeners.

No. of rivets = $\dfrac{417,000}{3 \times 4920}$ = 28

IV. Design of Reinforced Concrete Legs.

There are two ways in which reinforced concrete can be designed: (1) by means of longitudinal reinforcement, and (2) by means of bands or spirally wound metal. In the first, the steel carries the stress directly, and in the second laterally, to

prevent lateral expansion and thus strengthen the concrete.

(A) Column with both Longitudinal and Hooped Reinforcement.

(1) Long Column Formula:

Rankine's formula, $P'' = \dfrac{P'}{1 + \frac{f}{\pi^2 E}\left(\frac{l}{r}\right)^2}$ is to be used.

P'' = strength of a long column

P' = strength of a short column

f = ultimate strength

E = modulus of elasticity

l = length of column

r = radius of gyration

Transforming the equation it becomes

$$P'' = \frac{P'}{1 + \frac{1}{10,000}\left(\frac{l}{r}\right)^2} \qquad (1)$$

(2) Short Column Formula:

If, A = cross section of column

A_c = " " of concrete

A_s = " " of steel

p = ratio of steel to total area of column

f_c = stress in concrete

n = ratio of moduli of steel and concrete at the given stress, $f_c = \frac{E_s}{E_c}$

P = total strength of a plain column for the stress, f_c

P' = total strength of a reinforced column for f_c

Then the following is true:

$$P = f_c A$$

$$A_s = A \times p \qquad (2)$$

$$A_c = A - A \times p \qquad (3)$$

$$f_s = nf_c \qquad (4)$$

and $$P' = f_c A_c + f_s A_s \qquad (5)$$

Substituting (1), (2), and (3) in equation (4)

$$P' = f_c(A - A \times p) + nf_c A \times p$$

whence $$P' = f_c\, A[1 + (n - 1)p] \qquad (6)$$

(3) Combining (1) and (6) and substituting r, by its value, $\sqrt{\frac{I}{A}} = \frac{d}{2}\sqrt{3}$ [square column], (6) is changed to,

$$P' = \frac{P''(30{,}000d^2 + 41^2)}{30{,}000d^2}$$

Then, $$\frac{P''(30{,}000d^2 + 41^2)}{30{,}000d^2} = f_c d^2[1 + (n - 1) \times p]$$

Assuming, f_c = 600 pounds per square inch

p = 1.5 o/o

and, l = 80 feet

As before P'' = weight on one support = 417,000 pounds.

Solving for d and replacing algebraical values by their numerical values,

$$\frac{417{,}000[30{,}000d^2 + 4(12 \times 80)^2]}{30{,}000\ d^2} = 600d^2[1 + (15 - 1).015]$$

$$d^4 - 574d^2 - 70{,}500 = 0$$

$$d^2 = \frac{574 \pm \sqrt{574^2 + 4 \times 70{,}500}}{2} = 676.5 \text{ square inches.}$$

equal to the crossectional area

$$d = 26 \text{ inches.}$$

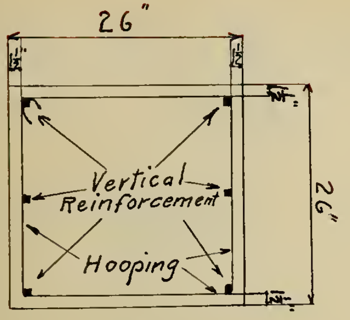


Fig. 6

(4) By table of Corrugated Bar Company for a column of 26" x 26" and $f_c = 600$ pounds, 6 - 1 1/8" C. R. is to be used. The standard hooping for this type consists of 1/4" round steel rods bent to enclose vertical reinforcing rods and spaced approximately 12" apart.

V. Design of Bracing.

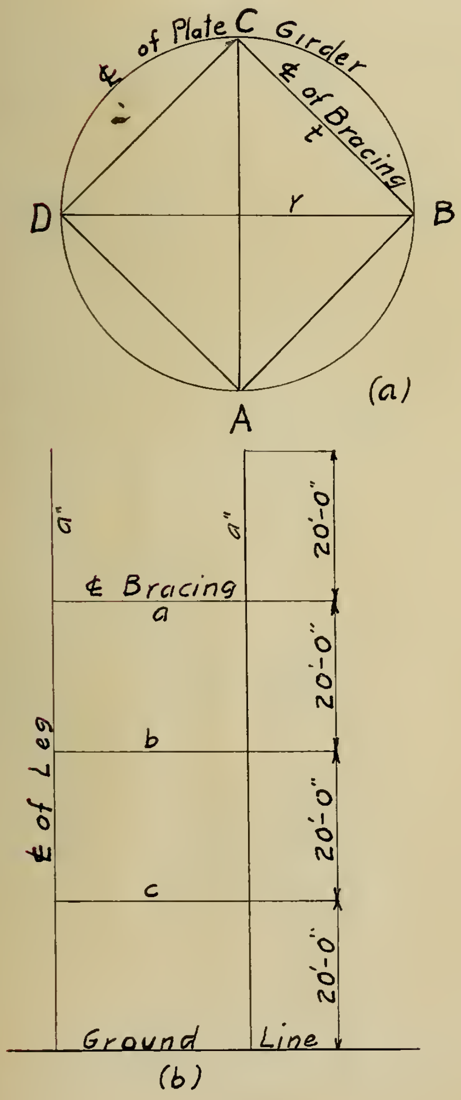


Fig 7

(A) $t = \sqrt{12.5^2 + 12.5^2} = 17.6$ feet

If, f_c = 700 pounds per square inch

P = 1.1 o/o

b = 10 inches (width of bracing)

WL = 50 pounds per square foot plane surface (wind load)

Wind load taken by bracing "a" = WL in a + WL in a' + WL in a"

Length of a = 17.6 + 2(26/12 x .707)

= 17.6 + 3.06 = 20.66 feet.

Then, Wind Load on bracing:

$$20.66 \times 50 \times 10/12 + 2\left(20 \times \frac{18.38}{12}\right)50$$

= 3924 pounds

(B) $M = \frac{1}{8} WL$

$= \frac{1}{8} \cdot 3924 \times 20.86 \times 12$

123,000 pound inches.

In, $R = \frac{M}{bd^2}$, R = 130 (by table)

Substituting the known values and solving for the unknowns,

$$130 = \frac{123,000}{6 \times 18.38^2}$$

$$b = \frac{123,000}{130 \times 18.38^2} = \frac{123,000}{44,000} = 2.79 \text{ inches.}$$

Then b can be used as assumed, 10 inches.

Crossection of steel = 10 x 18.38 x .011 = 2.02 square inches

using square bars, 4 - 3/4 inch.

(C) Design of Cross-Bracing.

The cross bracing is designed as a short column.

Wind pressure = 20 x 26/12 x 50 = 2170 pounds.

Substituting in formula, $P' = Af_c[1 + (n - 1)p]$

$$2170 = 700d^2[1 + (15 - 1) .011]$$

$$d^2 = 217/69 = 3.15 \text{ square inches.}$$

Then take d = 8 inches, Steel = 64 x .011 = .704

2 square bars, 5/8 inch.

(D) To provide for freezing, as the delivery pipe goes through the center it is necessary to cover it as shown in Fig. (8), a kind of insulator.

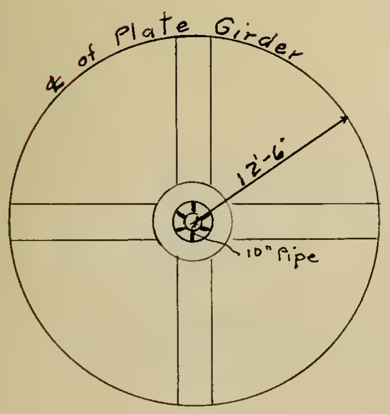
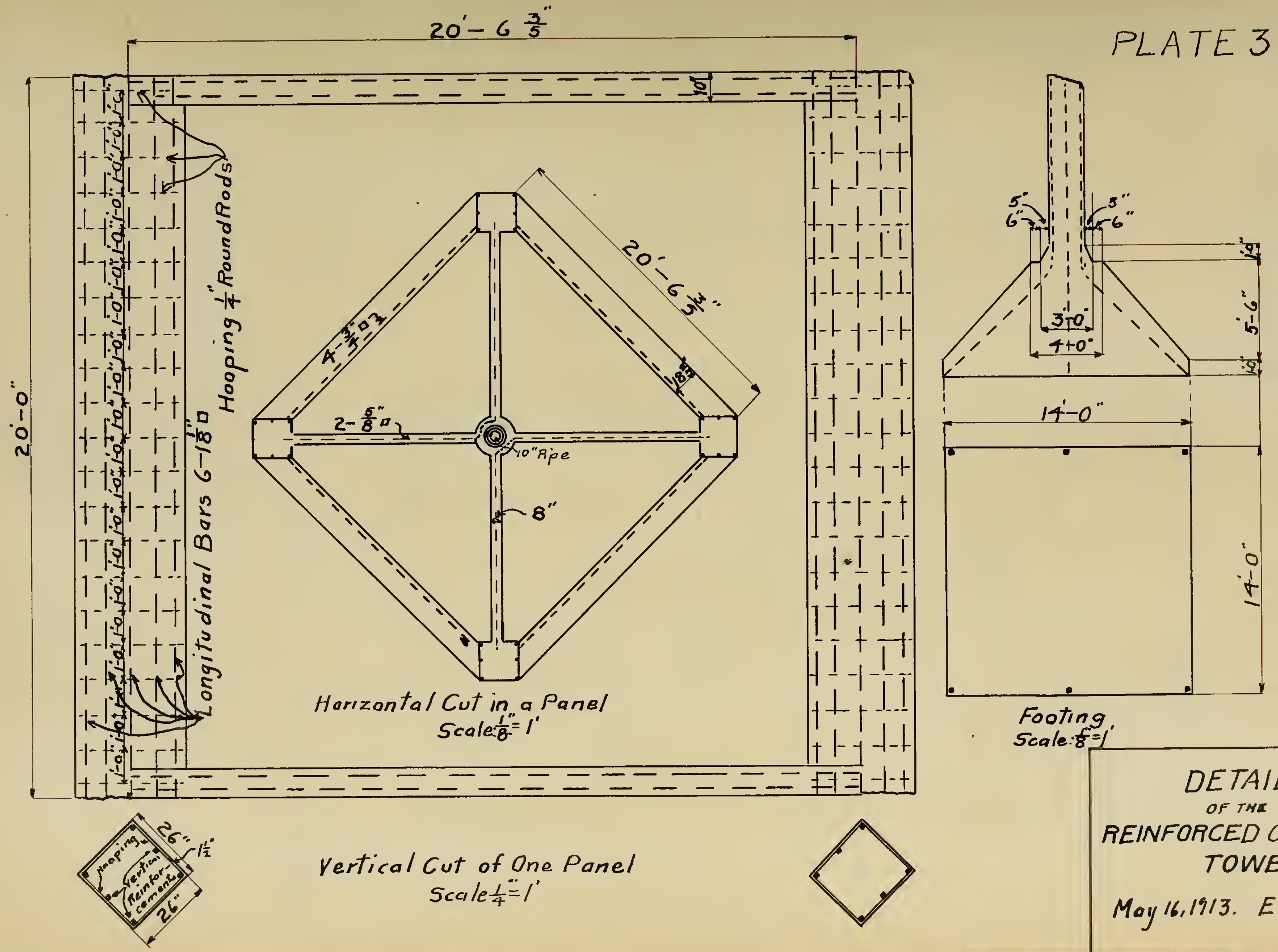


Fig 8

PLATE 3



DETAILS
OF THE
REINFORCED CONCRETE
TOWER

May 16, 1913. E. Fajardo

VI. Overturning Moment.

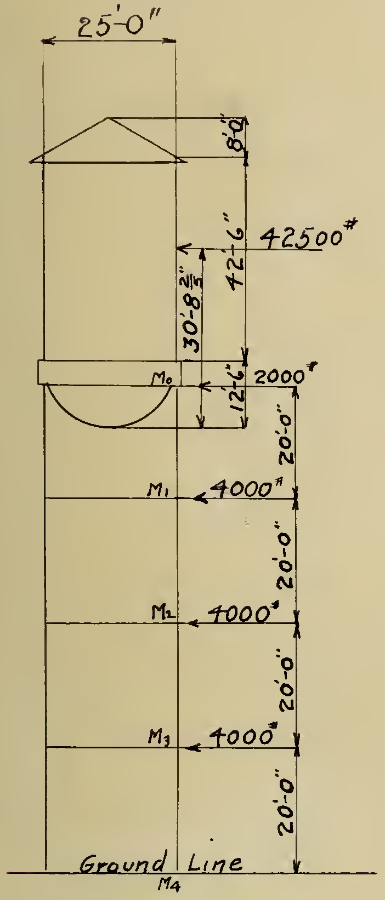


Fig 9.

(A) Center of Gravity of Superstructure.

Roof = 13.5 x 8.5 = 115 square feet.

Shell Cylinder = 42.5 x 25 = 1060 " "

Bottom = $\frac{0.7854 \times 25^2}{2}$ = 244 " "

Total 1419 " "

Static Moment

Roof 115(2.8 + 42.5 + 12.5)

= 6650 pound-feet

Shell cylinder

$1060(\frac{42.5}{2} + 12.5) = 35600$ " "

Bottom

244(12.5 - .424 x 12.5)

= 1295 " "

Total 43,545 pound-feet

Distance of center of gravity above bottom line = $\frac{43,545}{1419}$ = 30.7 feet.

(B) Wind Loads.

Total wind load on tank at 50 pounds per square foot over 60 o/o diametrical plane = 1419 x 60 x 50 = 42500 pounds.

Assumed wind load on tower, 200 pounds per vertical foot.

Wind load at base of plate girder = 200 x 10 = 2000 pounds

Wind load at first strut line = 200 x 20 = 4000 "

Wind load at second strut line = 200 x 20 = 4000 "

Wind load at third strut line = 200 x 20 = 4000 "

(C) Moments.

Moment at the top of column $M_0 = 42,500[30.7 - (12.5 - 5)]$
985,000 pound-inches

Moment at base of tower:

$M_4 = 42,500(30.7 + 80)$	=	4,710,000	pound-inches
2,000 x 80	=	160,000	" "
4,000 x 60	=	240,000	" "
4,000 x 40	=	160,000	" "
4,000 x 20	=	80,000	" "
Total	=	5,350,000	pound-inches.

(D) Resistance Moment.

The above overturning moment is resisted by the weight of the tank metal multiplied by its leverage, or, in this case, by the radius of the tank: then,

$M = 100,000 \times 12.5$

$= 1,250,000$ pound-feet.

As this is larger than the overturning moment the bolts used to hold the tank on the supports will be the minimum size specified. By Ostrup's specification, 7/8 inch bolts are the minimum.

VII. Foundation.

To design the foundation we have to take account of the dead load and wind load in the columns plus the additional weight of the pier itself. Assume the weight of a cubic foot

of concrete to be 145 pounds.

Total weight of water on one pier,

plus weight of structure above column = 417,000 pounds

Weight of one leg = $80(\frac{26}{12})^2 \times 145$ = 54,000 "

Total wind load on one pier = 217,000 "

Weight of Bracing = 8,423 "

Total = 696,423 pounds

Approximate base required = $\frac{696,423}{4,000}$ = 174 square feet

d = 13.2 feet (assuming two tons taken by ground)

Volume of footing = $13.2^2 \times 1/3x(13.^2 \times 8 - 4^2 \times 2.5) + 3^2 - 26/12)^2$

= 611 cubic feet.

Weight of footing = 611 x 145 = 88,700 pounds

Adding this weight to the total above found we have 776,700 pounds.

Then, the area required = $\frac{776,000}{4,000}$ = 194.2

or, d = 14 feet.

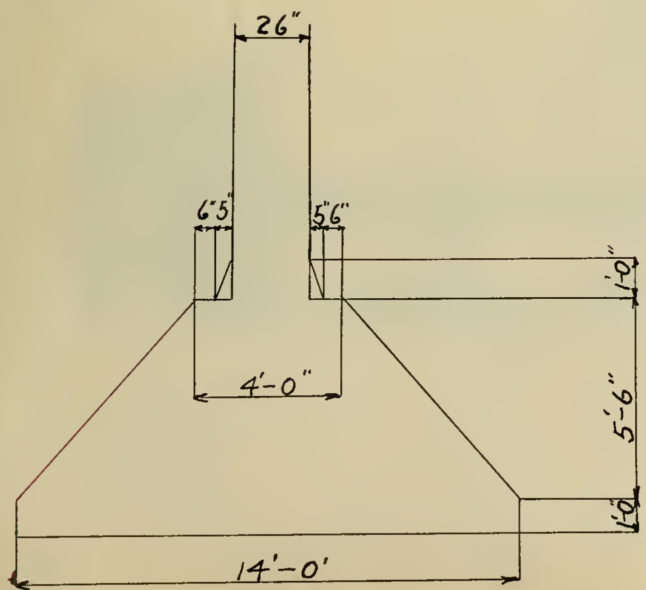


Fig 10

Patented Elliptical Bottom Tank with Parabolic Posts

Capacity, 200,000 gallons — Height to bottom, 86 feet
Atchison Water Co., Atchison, Kansas

The First Tank of this Type

Capacity, 104,000 gallons — Height to bottom, 84 feet
City Water-Works, Fort Dodge, Iowa

Standard One Panel Tower

Capacity, 50,000 gallons Height to bottom, 21 feet
City Water-Works, Madill, Oklahoma

Standard Two Panel Tower

Capacity, 100,000 gallons Height to bottom, 61 feet
Nevada Northern Ry. Co., East Ely, Nevada

Standard Three Panel Tower

Capacity, 100,000 gallons Height to bottom, 110 feet
City Water-Works, Plymouth, Indiana

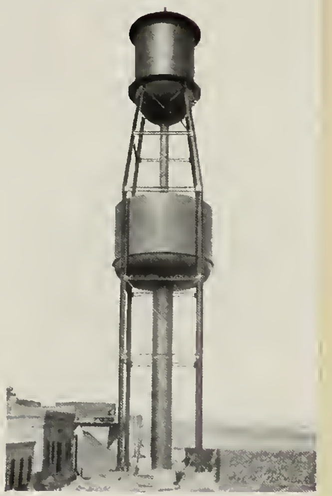
Standard Four Panel Tower

Capacity, 70,000 gallons Height to bottom, 115 feet
Ballard & Ballard, Louisville, Kentucky

Baltimore, Md.
Capacity, 100,000 gals. Ht. 89 ft.
Capacity, 20,000 gals. Ht. 60 ft.
Baltimore Sewerage Commission

Rochelle, La.
Capacity, 50,000 gals. Ht. 80 ft.
Capacity, 15,000 gals. Ht. 50 ft.
Tremont Lumber Co.

Oakley, Ohio
Capacity, 75,000 gals. Ht. 100 ft.
Capacity, 50,000 gals. Ht. 50 ft.
The Factory Power Co.



Detroit, Mich.
Capacity, 50,000 gals. Ht. 100 ft.
Capacity, 100,000 gals. Ht. 50 ft.
Detroit Sulphite Pulp & Paper Co.

Double Tanks for Sprinkler and Domestic Service
Height given to bottom in each case

Standard Hemispherical Bottom Tank

Capacity, 1,200,000 gallons — Height to bottom, 130 feet
Diameter of tank, 50 feet — Height of tank, 90 feet
Louisville Water Co., Louisville, Ky.

The largest tank of this type yet built

Fort Frances, Ont., Canada
Capacity, 100,000 gals. Ht. 81 ft.
City Water Works

Edmonton, N. W. T., Canada
Capacity, 75,000 gals. Ht. 56 ft.
City Water Works

Brazil, S. A.
Capacity, 100,000 gals. Ht. 30 ft.
Madeira, Mamore R. R. Co.

Cananea, Sonora, Mexico
Capacity, 40,000 gals. Ht. 75 ft.
Cananea Consolidated Copper Co.

Tanks in Foreign Countries
Height given to bottom in each case

Peru, South America
Capacity, 15,000 gals. Ht. 12 ft.
Central Ry. of Peru

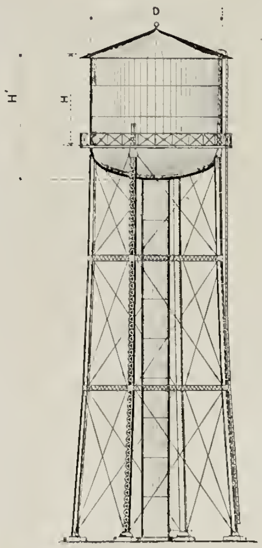
Havana, Cuba
Capacity, 20,000 gals. Ht. 25 ft.
Western R. R. Co.

Manila, Philipine Islands
Capacity, 100,000 gals. Ht. 41 ft.
U. S. Naval Station

Pekin, China
Capacity, 50,000 gals. Ht. 100 ft.
Bureau of Engraving & Printing

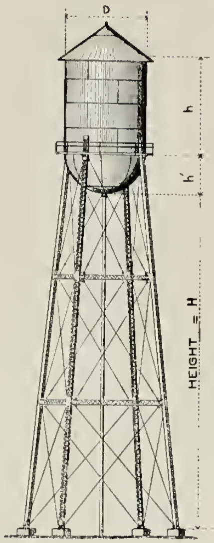
Tanks in Foreign Countries
Height given to bottom in each case

Dimensions of Our Standard Patented Elliptical Bottom Tanks for Which We Have Drawings and Templates on Hand



Capacity Gallons	Diameter Feet D	Height Feet H	Height Feet H'
5000	10'0"	7'0"	9'6"
10000	13'0"	8'0"	11'3"
15000	15'0"	9'0"	12'9"
20000	16'0"	11'0"	15'0"
25000	17'6"	11'0"	15'4½"
30000	18'6"	12'0"	16'7½"
35000	19'0"	13'4"	18'1"
40000	20'0"	13'9"	18'9"
45000	22'0"	10'6"	16'0"
50000	22'0"	14'0"	19'6"
60000	24'0"	14'0"	20'0"
65000	24'0"	15'6"	21'6"
70000	25'0"	15'0"	21'3"
75000	26'0"	15'0"	21'6"
80000	26'0"	16'0"	22'6"
90000	28'8"	14'0"	21'2"
100000	28'8"	16'0"	23'2"
120000	32'0"	14'8"	22'8"
125000	32'0"	15'6"	23'6"
150000	34'0"	16'6"	25'0"
175000	36'0"	17'6"	26'6"
200000	38'0"	17'6"	27'0"
225000	38'0"	20'4"	29'10"
250000	40'0"	20'0"	30'0"
275000	40'0"	22'9"	32'9"
300000	41'0"	23'9"	34'0"
350000	44'0"	22'6"	33'6"
400000	47'0"	23'0"	34'9"
450000	49'0"	24'0"	36'3"
500000	51'0"	24'3"	37'0"
750000	58'0"	28'6"	43'0"
1000000	64'0"	32'0"	48'0"

Dimensions of Our Standard Tanks, for Which We Have Drawings and Templates on Hand.



Capacity Gallons	Diameter Feet D	Height Feet h	Width of Balcony Inches
15000	12'0"	14'0"	18
20000	12'9"	17'3"	18
25000	14'1"	17'3"	18
30000	15'3"	17'3"	24
35000	16'4"	17'3"	24
40000	17'4"	17'3"	24
45000	18'3"	17'3"	24
50000	19'0"	17'6"	24
55000	19'0"	19'11"	24
60000	19'0"	22'3"	24
65000	20'0"	21'3"	24
70000	21'0"	20'3"	24
75000	22'0"	19'4"	24
80000	22'0"	21'1"	27
85000	22'0"	22'9"	27
90000	22'0"	24'6"	27
95000	22'0"	26'0"	27
100000	22'0"	28'0"	27
105000	23'0"	26'0"	27
110000	23'0"	28'0"	27
115000	24'0"	26'0"	30
120000	24'0"	28'0"	30
125000	24'0"	29'0"	30
130000	25'0"	27'0"	30
140000	25'0"	30'0"	30
150000	25'0"	33'0"	30
175000	26'0"	35'0"	36
200000	28 0"	35'0"	36
250000	30'0"	37'0"	36
300000	32'0"	40'0"	36

Rule for finding size of base:

Diagonal $= D + .23\ (H + h')$ } Closely
Square $= .71\ D + .162\ (H + h')$ } Approximate

Depth of bottom $h' = \frac{D}{2}$